EFFECTS OF THE INHERENT OPTICAL PROPERTIES ON REMOTELY SENSED REFLECTANCE

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LONG-TERM GOALS

The long-term goals of this project are to determine how the inherent optical properties and their vertical distribution affect remote sensing.

SCIENTIFIC OBJECTIVES

This work includes using two-flow and full radiative transfer models to evaluate the conditions under which subsurface optical structure is detectable, and to develop an inversion model to determine the vertical structure of the IOP based on the presence of horizontal gradients in the spectral reflectance. We are also examining the role of the volume scattering function in determining the measured reflectance.

APPROACH

This project is being conducted in close collaboration with Emmanuel Boss of the University of Maine under project N000140310339.

The components of our approach are:
1. Evaluate the conditions under which subsurface optical structure is detectable,
2. Develop an inversion model to determine the vertical structure of the IOP based on the presence of horizontal gradients in the spectral reflectance,
3. Examine the effects of changes in the volume scattering function on the reflectance,
4. Evaluate the model using field data.

An analytical model was developed to examine the conditions that subsurface optical structure may be detectable. We will use measurements collected during the field experiments at the LEO-15 site to test models for inverting to get optical structure. Data collected during the field experiments includes several measures of the volume scattering function under a wide range of conditions. These measurements will be used to examine if the volume scattering function is important in determining the reflectance under single-scattering conditions.

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The ability to use remotely sensed radiance to determine vertical structure depends on the optical properties and thickness of the surface mixing-layer (ML). In this region the physical processes are assumed to mix particles and dissolved materials faster than source or sink terms for the given material, which gives rise to a layer in which the optical properties can be assumed to be homogeneous. Such a surface-mixing layer is formed by the action of wind, waves and convection.

Light penetration through the surface layer depends on the optical properties of the surface layer and its thickness. To be detectable, stratification in optical properties must exist within the satellite viewing depth and there must be sufficient contrast between the surface layer and those beneath it. Since $R_{rs} \propto \frac{b_b}{a_t}$, no contrast will exist if both the backscattering (b_b) and total absorption (a_t) change by the same proportion between the surface and lower layers. It can be shown that the solution to the radiative transfer equation at a fixed optical depth (such as in the case of water leaving radiance) will remain constant if the IOP co-vary (i.e. a/b, a/c, b/c are constant) and the shape of the phase function is constant. We will refer to cases where the optical properties co-vary, as being vertically optically homogeneous because an equivalent homogeneous distribution of IOP exists that would provide the same reflectance. Optical homogeneity in the vertical requires that both the backscattering and total absorption increase by the same proportion, which is more likely to occur at shorter wavelengths. This is because the total absorption coefficient is dependent on the contributions by water, CDOM, and particles (phytoplankton, detritus, and sediment) and in coastal waters particles alone dominate b_b. For both b_b and a_t to change by the same proportion the optical properties must be dominated by the particles. In the red portion of the spectrum water has a large absorption coefficient and it is therefore less likely that particles will dominate the optical properties. Thus it is most likely that vertical optical homogenity will affect only a part of the spectrum.

In evaluating the role of the volume scattering function we are working closely with a group of investigators from the Marine Hydrophysical Institute in the Ukraine who measured the volume scattering function during the field experiments. We also are working with them and others to investigate the instrument capabilities and scattering properties of individual organisms as part of a scattering workshop.

WORK COMPLETED

We have completed two field campaigns at the LEO-15 site. In the summer of 2000 we concentrated our measurements close to shore where the surface waters were very turbid. In the summer of 2001 we focused our efforts further offshore where clear over turbid conditions prevailed. We were also able to sample a wide range of optical water types at stations running from the LEO nodes to the shelf break. Data from these cruises are available through our website http//photon.coas.oregonstate.edu/ocean/projects/hycode/data/hycode_data.html. In the spring of 2002 we participated in 2 scattering workshops. The first examined the performance of a wide range of instruments that measure scattered light and the second examined the scattering properties of phytoplankton cultures.

We examined the role of the subsurface structure in the IOP on the remotely sensed reflectance off the LEO-15 site during 2001. We examined the limitations of the various published inversion models designed to retrieve the IOP from remotely sensed reflectance. We were involved with a study to

predict the optical properties during the HyCODE experiment, and another to examine the closure of upwelling radiance with the IOP. All of these studies were presented during the Ocean Sciences meeting in 2002. An additional study presented at Ocean Science and published in Applied Optics (Boss and Pegau, 2001) examined the retrieval of the backscattering coefficient by measurement of scattering at a single angle. Further work with the scattering and attenuation by particles led to the publications on the phase function effects on oceanic light fields (Mobley et al., 2002), the determination of the size distribution of particles from the beam attenuation spectrum (Boss et al., 2001), and inversion of reflectance to determine the beam attenuation spectrum (Roesler and Boss, 2003). Further work with the IOP led to publications on the closure of upwelling radiance estimates with the IOP (Chang et al., 2002), the physical forcing factors determining the distribution of IOP (Chang et al., 2003), and the determination of circulation patterns using ocean color measurements (Pegau et al., 2002). We have also completed a study on the relation of scattering and particle composition in the vicinity of Leo XV (Boss et al., in press). A graduate student from Oregon State University, Megan Carney, has completed an analysis of IOP inversion algorithms and the robustness of the c_p spectrum versus size distribution relationship.

It is our desire to invert remote sensing data to determine the subsurface structure in IOP. To date we have not found a complete data set to do the inversion with. The noise level in the TSRB data is of the same magnitude as the expected signal. The overflight data only once extended to the area that we expect to be able to observe subsurface structure. That data still remains to be atmospherically corrected before it can be used in inversion algorithms. The hyperspectral upwelling reflectance data collected by the Dalhousie group remains the one data set that we must determine if it may be of use for our investigation. An analysis of a partial data set from East Sound, WA, to obtain subsurface IOP structure has been performed (Barnard, 2001) and we anticipate it being sent to publication in the next few months.

RESULTS

The optical properties observed during the 2001 field campaign showed a front in optical properties near the 25 m isobath and offshore of the front a subsurface chlorophyll layer extruded outward with a core at approximately 18 m depth. This turbid water was overlain by very clear water, which provided ideal conditions for observing subsurface structure. In this case we found that the absorption in the subsurface layer reduced the water-leaving radiance by 4% at blue wavelengths, and the increased backscattering increased the water-leaving radiance by up to 10% at 550 nm compared to the case where the subsurface layer did not exist. Modulation of the subsurface layer by a 1 m amplitude internal wave would cause approximately a 2% change in reflectance between the peak and trough with larger waves causing larger changes in reflectance.

Improvement of algorithms for inverting ocean color to obtain IOPs is crucial for this project. In Roesler and Boss (2003) we have developed a novel approach to inverting ocean color. Rather than assuming a shape for the particulate backscattering spectrum (as commonly done) we expressed it as a function of particulate attenuation and absorption, two better constrained IOPs (designated below as c-based model).

The model was tested on data collected from a range of optical environments with chlorophyll values ranging from 0.07 to 131. 65 μg/L. Reflectance spectra were well predicted by both the standard and

the c-based inversion models under typical gyre and coastal regimes, although the c-based model predicted the measured reflectance better under the extreme algal bloom.

The c-based model performed better than the standard model in predicting the magnitude of the particle backscattering coefficient and the magnitude and spectral shape of the particulate and CDOM absorption coefficients. The standard model overestimated both the backscattering and absorption coefficients. The spectral slopes on the derived backscattering coefficients were very steep (and unrealistic) but were balance by transference of variance to the CDOM and CPM constituents. Particulate attenuation coefficients derived from the c-based model compared well with observed values over three orders of magnitude, with a slope of 0.73 for the whole data set and a slope of 1.01 for values less than 1.5 m^{-1} and $r^2 = 0.83$ regardless of range. Similarly, the particulate absorption coefficient derived by the model was highly correlated with observed values, r^2=0.81, with a slope of 1.05. The values derived for the particle backscattering ratio varied from 0.005 to 0.01, which was in the range of observed values (0.005 to 0.015) but were uncorrelated. The values derived for the slope of the particle attenuation coefficient, γ, were likewise within reasonable ranges but were only weakly correlated with observed values, r^2=0.57, with a slope of 0.64 (Fig. 1).

In 2003 we started working on assessing the uncertainties associated with inversion of remote sensing. Currently, inversion product are ‘error free’, e.g. no attempt is done to provide a likely range for the inverted product (e.g. what is the 95% confidence interval for the value of CDOM absorption at 440nm?). This problem is the Master thesis topic of Wang Peng at University of Maine. We expect a manuscript on the subject to be submitted to Applied Optics within 10 months.

An investigation of the relationship between the c_p spectrum and the size distribution has been conducted by Megan Carney at Oregon State University as part of her Master thesis. She has found that there is a correlation between the two parameters, but it is very sensitive to the fitting parameters applied to the size distribution data. A manuscript and thesis describing this work is expected by January 2004.

We are currently collaborating with Jennifer Prentice of NavAir, Allan Weideman of NRL and Andrew Barnard (WetLabs) on linking LIDAR measurements performed at LEO 15 in 2001 to the in-situ IOPs. The LIDAR signal emanating from depth z is proportional to the VSF near 180 degrees times twice the attenuation from the surface down to that depth. If we understand the relationship between the LIDAR measurement and the IOPs we could use LIDARs to obtain the vertical distribution of IOPs.

In August 2003, using startup funds from University of Maine and some ONR funds, we began investigating the relationship between acoustical and optical scattering in an estuary (SOAP, spectral Optical and Acoustical Playground). In collaboration with Pete Jumars and Lee Karp-Boss of the University of Maine, Paul Hill of Dalhousie and Collin Roesler of Bigelow Labs, we measured remotely sensed reflectance, in-water IOPs, in-water multi-frequency acoustical backscattering, images of the in-situ particles, and biogeochemical variables. The data is currently being analyzed.

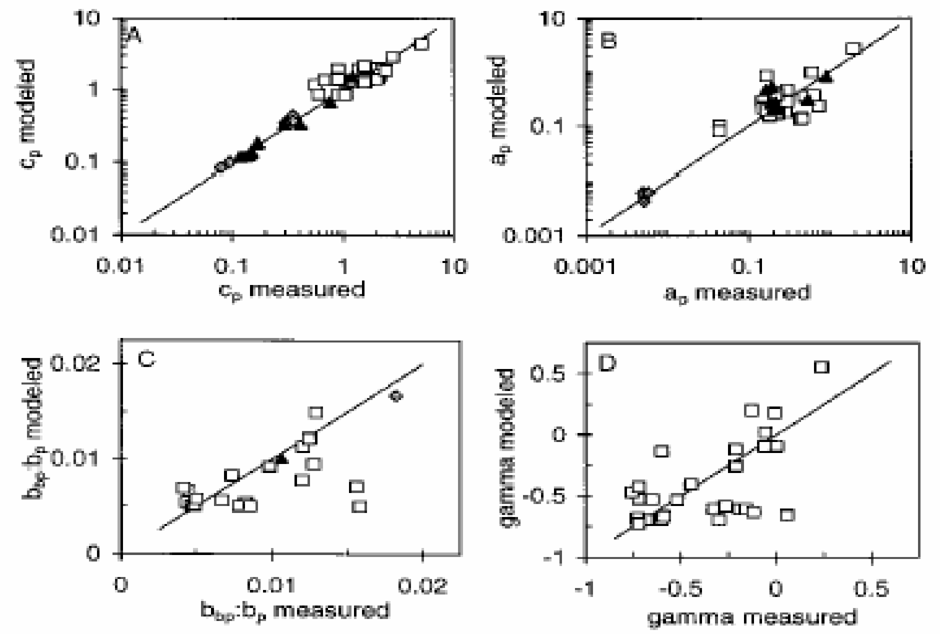

Figure 1. Measured vs. modeled optical properties:[particulate attenuation (A) and absorption coefficients (B) at 440nm, particulate backscattering ratio at 650nm (C; 532 nm for gyre and Gulf of Maine), and slope of the particulate attenuation spectrum (γ, D). Symbols: gyre - gray diamond, Gulf of Maine - black triangle, Benguela Upwelling – open square.]

IMPACT/APPLICATIONS

Providing information on the vertical distribution of IOP will enable more exact inversion of ocean color to optically active water constituents. The estimation of the backscattering coefficient by instruments making measurements at a single angle can be improved by treating the water and particulate components separately. Improving ocean color algorithms will provide better information on the distribution of in-water IOP.

TRANSITIONS

Work on the scattering shape of the scattering function conducted within this project has been used by WETLabs to modify their backscattering sensor and calibration procedure. Analysis of the separation of water and particulate scattering in determining the backscattering coefficient has influenced a change in the analysis software for the Hydroscat from HOBILabs.

RELATED PROJECTS

None

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